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D03932

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Original: ENGLISH

Symposium on the Development of the Plastics
Fabrication Industry in Latin America

Bogotá, Colombia, [illegible] November – 1 December [illegible]

PAPER-LIKE FILM FROM HIGH DENSITY POLYETHYLENE [1]

by

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SUMMARY

PAPER-LIKE FILM FROM HIGH DENSITY POLYETHYLENE[1]

by

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The development of paper-like, high density polyethylene films began about three years ago in South Africa. "Paper-like" does not, of course, refer to all properties. Such films, in fact, combine the desirable properties of polyolefin films, e.g. waterproofness and imperviousness to gases, wet strength and weldability, with paper properties such as stiffness, mat surface, good folding performance and printability. This article is devoted to descriptions of the raw materials used, the manufacturing processes employed, the machines that are suitable and application possibilities.

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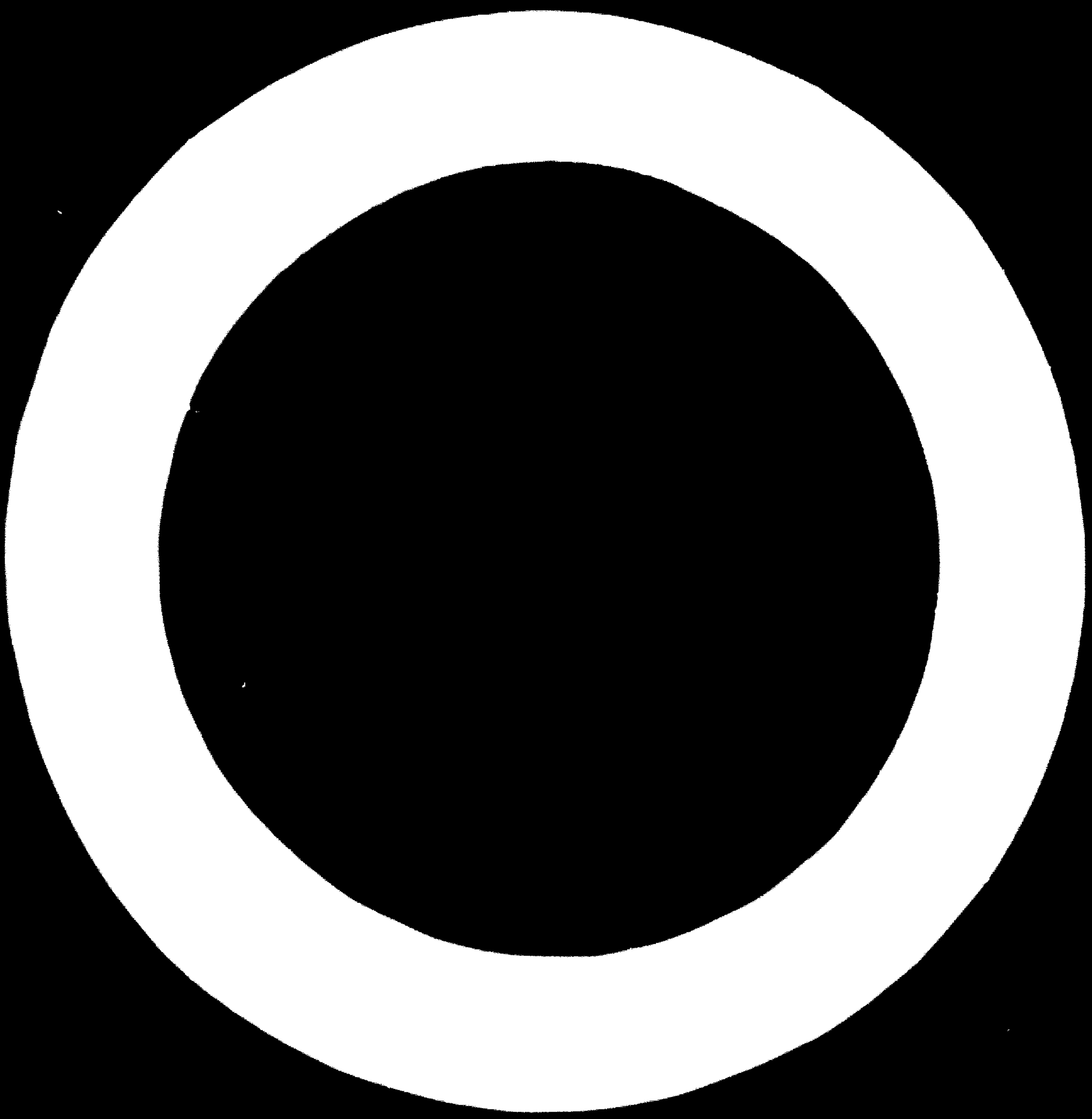


I. Paperlike Film made from Low Pressure Polyethylene

The development of paperlike low pressure polyethylene (LP-PE) films started about three years ago in South Africa. The term "paperlike" does of course not refer to all properties. Such sheets rather combine the good properties of polyolefine sheets such as water and gas tightness, wet-strength and weldability, with properties of paper such as great stiffness, matt surface, good creasability and printability. A survey is given of the raw materials used, the processing methods applied, the machines used and also the range of applications.

When examining the recent development of synthetic paper or so called paperlike sheets, one has to distinguish clearly between two types, i. e. the development of packaging sheets and that of synthetic print carriers.

The development of sheets to replace graphic papers (synthetic papers) takes place at present mainly in Japan but also in Europa. The best known sheets are Q-Kote(R), Q-per(R) and Acroart(R). These are mainly polyethylene or polystyrene sheets which have undergone after-treatment for their improvement. Papers made from synthetic fibres are also known (Pretex(R), Neoband(R), Typar(R), Tyvec(R)), but are not being discussed here.

Experiments to produce papers from LP-PE, are as old as high density polyethylene itself. In the past these experiments met only with limited success for some special applications whether produced by the flat sheet or by the blowing process. These experiments were only resumed when the technology of extrusion plants and that of raw materials had sufficiently progressed. These new attempts have been taken place on a broad front for the last three years, aiming particularly at the production, not only of LP-PE-sheets, but at paperlike sheets made from LP-PE. This development started in South Africa, where a particularly favourable price ratio exists between low density and high density PE, followed by Japan due to the high paper price there and finally in Europe in spite of the cost position here being worse than in the other countries mentioned. We will be reporting here exclusively about these paperlike sheets made from LP-PE. They are produced exclusively by the sheet blowing process.

The term "paperlike" is not to imply that all properties of these sheets correspond to those of paper. Such sheets rather combine the good properties of polyolefines such as good water and gas tightness, wet-strength and weldability, to a large degree with the good properties of paper such as great stiffness, matt surface, good foldability and creasability and also good printability. Paperlike sheets made from LP-PE will therefore have to be considered in future not only in competition with traditional packaging papers but also with high pressure-PE-(HP-PE) sheets.

II. Raw Materials

In the main two LP-PE-grades of different molecular weight are available for the manufacture of paperlike sheets. Whilst LP-PE of medium molecular weight (M 50,000 to 80,000, MFI 190/5 1.5 to 5.0 g/10 min) will yield sheets corresponding in their mechanical properties to experiences made hitherto, high molecular LP-PE (M 90,000 to 120,000 MFI 190/5 0.2 to 0.6 g/10 min) will produce sheets excelling by their great strength and stiffness. These sheets are produced from high molecular raw materials and have become known as HM-sheets (HM stands for high molecular).

When processing low molecular **weight raw amterials a comparatively** low blowing ratio is used, i. e. the stretching ratio along and across the direction of processing is not levelled out, because no increase of strength would result from a higher blowing ratio. The resulting sheets are therefore oriented mainly monoaxially.

In contrast to this HM-sheets are produced with a high blowing ratio (1 : 4 to 1 : 10). These sheets have a better levelled out orientation in the longitudinal and transverse directions and thus better levelled properties and greater strength.

Basically it is possible to produce LP-PE-sheets from raw materials in powder or in granule form. Colouring may be carried out prior to granulating, or afterwards by adding colour concentrates. Antistatic agents may also be added to the raw material, however, if thin film is to be blown, antistatic treatment becomes somewhat problematic.

III. Process

To obtain maximum paperlikeness, some special factors must be observed during sheet manufacture:

1. To achieve a matt, finely roughened surface and mechanical properties well balanced in both directions it is important to extrude at the lowest possible melt and blow head temperatures and to apply the highest possible blowing ratio (1 : 4 to 1 : 10).
2. To obtain strong and stiff sheets, high molecular raw materials are being used.
3. The hose is being blown partially within the crystallite melt region, which further increases the sheet strength. The reliable production of sheets from 10 to 100 μ thick is possible.

Processing of LP-PE, particularly high molecular grades, has its difficulties and makes great demands upon the working technique. It is rather difficult to melt high molecular LP-PE without local overheating and without excessive shearaction into a homogeneous mass. Owing to the linear non-branched molecular structure LP-PE tends to have a higher degree of melt orientation. This is particularly important, because the blowing temperatures are kept very low thus leading to high viscosity and requiring high extrusion pressure, both factors being important with melts already being oriented.

When designing a plant for the manufacture of HM-blown sheet it is important to consider for the design of the screw the optimum shape of the flow paths, the high extrusion pressures and the high blow-ratio. Only in this way it is possible to avoid inadmissible shearing of the material in narrow flow channels, the appearance of flow marks and overheating. The relationship of these factors is shown in table 2.

Lay-Out of Processing Plant

The design of screw-geometry is of paramount importance. The screw has to process a homogeneous melt which should be as cool as possible. Too high a mass temperature results in greasy lustre of the sheet surface and in the worst case in break down of the melt and thermal decomposition. This implies:

- No high screw revolutions.
- High specific output values G/n in order to achieve an economic output with medium to low revolutions.
- No constant deeply cut screw threads because this leads to shearing layers which cause inhomogeneity, break down of melt and thermal decomposition.

Fig. 1 very clearly shows test results with screws of different thread depth ratios. Three-zone screws were used with a thread depth ratio of 1 : 4, then with identical thread depth in the feed zone - screws with a thread depth ratio of 1 : 3 and 1 : 2 respectively. These were compared with a modified three-zone screw fitted with a compression and a pressure relief zone, see fig. 2.

These screws are characterized by a constantly deep cut feed zone (to ensure even feed), a compression zone of 6D to 8D length (to ensure careful melting) and a metering zone which starts with a zone of a few D-lengths of a shallow thread followed by a deeper cut thread acting as pressure relief zone.

Shearing components with a short and intensive shearing action, or those which act more as mixers may support homogenization or improve dispersion of colour pigments.

The recognised standard length of screws for sheet extrusion of LP-PE is 25D.
In order to improve the feed of fine or coarse powders the modern barrel is fitted with a grooved intensively cooled feed zone.

The sizes of the perforated discs and sieves used correspond to those usual for LP-PE, i.e. a set of sieves consists of two coarse and three fine sieves in conjunction with the usual perforated disc; this helps the homogenizing work done by the screw. The problem of automatically changing the sieve packets remains unsolved as yet. With the prevalent high extrusion pressures so far all known sieve change arrangement, such as magazine sliding devices or automatic sieve-bands have failed.

It can be concluded from the properties of the raw material - linearity and well defined memory of LP-PE - that special attention must be paid to the design of the blow-head, particularly if high molecular raw materiel is to be processed.

Basically the optimum design for a blow-head would be one which forms the melt into a hose without dividing the melt flow. Conventional blow-heads which do divide the melt flow have proved suitable in practice, provided they are fitted with devices superimposing a longitudinal or an enforced transverse current. Furthermore a large ratio of the cross section area at the parting (e.g. at the carrier ring) to the cross section area at the die orifice was found favourable. The following types of blow heads are at present used for the manufacture of LP-PE sheets, see fig. 4:

a) Mandrel blow-head of conventional design which suffers from two drawbacks - feed and confluence.
b) Blow-head designed by the Egan-principle which produces longitudinal and transverse currents, using control or side feeding.
c) Conventional central blow-head, but with high compression ratio between cross section area of carrier ring and area of ring slot.
d) Central blow-head with excessively long mandrel and nozzle attachments, giving correspondingly high nozzle resistance.
e) Central feed blow-head with perforated distributors ending in pockets. The perforated distributor is spread over two planes and the pockets of these two planes are arranged in offset positions.

Chromium plated as well as not plated tool surfaces with a roughness-depth of $\leq 2\ \mu m$ have proved themselves.
Medium molecular LP-PE for applications where a tendency of longitudinal splitting does not matter is processed exactly like HP-PE, i.e. with blow ratios between 1 to 1.8 and 1: 3, take-off speed and cooling effect of blowing air according to material output. When sheets are to produced with equal longitudinal and transverse properties, special problems arise through the necessary high blow ratio and with high molecular

materials through the great stiffness of the raw material, see fig. 4.

The position of the high elastic region blow the frostline - shows that longitudinal stretching produces less orientation than transverse stretching through blowing. It can be calculated approximately that the take-off ratio i_L may be twice the blowing ratio i_B in order to arrive at approximately equal properties in the longitudinal and transverse direction. See formula below.

$$i_B \, i_L \, \delta = s \, k$$

whereby δ = sheet thickness, s = slot width, K = swelling factor (ratio of specific gravity at 20° C and 0 atm. to the specific gravity at melt temperature and extrusion pressure). It follows that high blowing ratios must be used for the manufacture of very thin sheets with uniform properties in the longitudinal and transverse direction, see fig. 5. This may result in a long cylindrical sheet neck which has the advantage that the emerging melt can be rendered more uniform and be cooled slowly before the hose is widened to its final dimension.

To keep such a sheet bubble stable a blow ring lip designed to have a Venturi effect is available. Outer calibrations which provide exact guiding of the sheet bubble are also used. At present rigid calibrations made from perforated aluminium or sheet steel are in use, wire netting is also used. Calibrating devices with adjustable calibrating diameter are still in the development stage.

Lay-Flat which is the change over from a cylindrical sheet bubble to a double sheet laid flat is usually an unsuspected cause of trouble. A sheet can only be laid flat, without

any flows in flat laying, if the distance between the beginning of flat laying and frost line is correct and a suitable flat laying device is being used. This will be discussed in details later on.
When changing over from a cylinder to a double flat sheet, geometrical length differences arise. These secessitate a small flat-laying angle - usually 10° to 15° - so as to keep the "flat laying error", caused by partial lengthening of sheets within reasonable limits.

The great stiffness particularly that of high molecular raw materials and the greater sheet thickness require high flat laying temperatures of 60° to 80° C. This makes laying flat of sheets without wrinkling still possible at reduced stiffness.

The sliding sheet supports may be clad with paper, velvet or similar material, the frictional resistance of which towards LP-PE and their heat conductivity are low.

For the winding of paperlike sheets contact and also central-winders are used at present. When winding sheets more than 100/um thick, or when winding at speeds exceeding 50 m/min, contact winders show definite disadvantages compared with direct winders. However, owing to their low cost they are also provided for thicknesses and speeds which can to-day be operated safely.

When thin sheets are to be produced at high speeds, or thicker sheets, central winders with sheet-tension regulators are advantageous.
For trimming edges or for cutting into strips, the same cutting gear is used as for cutting HP-PE sheets. The same applies to print - pretreatment plants using Corona discharge.

Production of Precisely Flat Lying Cylindrical Windings

For the manufacture of sheets for further processing it is absolutely imperative to use blow-heads wich produce with only a minimal thickness tolerance and to produce rolls free from "piston rings", which can be achieved by a part of the plant rotating.

Possible sources of errors in thickness tolerance of the sheets are:

a) the screw
b) the blow-head
c) the cooling ring
d) the environment (e.g. draft)
e) the laying flat.

By rotating parts of the plant these faults can be spread over the whole width of the sheet as follows:
Rotating blow-head faults from b and c.
Rotating extruder faults from a, b and c, and only by rotating take-off and lay flat faults from a to d.

When processing LP-PE at high blow rate and high take off speed after-shrinkage is impeded if the rolls are free from "piston rings" and if the widing is absolutely cylindrical and plane. After-shrinkage is the tendency of the sheet to shrink at room temperature. This process does not start until hours after processing and ends after some days. E. g. the longitudinal shrinkage in dependence on sheet thickness may amount to 3 to 5%. The consequence may be that the sheet contracts on this spots, caused e.g. by environmental effects on the bubble and tightens on the roll, forming wrinkles, thus the winding diameter is reduced. Such a sheet has partial strips of good and bad flatness and is unsuitable for use on fast running automatic machines.

In principle it is possible to exclude after-shrinkage by heat treatment of the sheet. However this requires additional machinery or devices and also energy. It is however better to keep this effect so small that it does not interfere with further processing, by suitable design of the sheet blowing plant and by exact adjustment of cooling and flat laying conditions to processing data.

To obtain cylindrical windings of uniform winding hardness it is essential that the sheet blowing plant distributes as far as possible all effects of faults, furthermore the correct position of the frost line in relation to laying flat is also essential.

Three possibilities of setting up the frost line are shown in fig. 6. In the arrangement shown in fig. 6a the points touched first cool faster and remain thicker. The resulting windings are not cylindrical and unsuitable for most applications.

In the arrangement in fig. 6b the sheet is already cooled too much.
Owing to the great stiffness of the sheet particularly at greater sheet thicknesses it will not be possible to lay the sheet flat when using this arrangement.

In the arrangement shown in fig. 6c the frost line is correctly placed in relationship to flat laying, therefore winding with exactly uniform winding hardness is possble and if wound sufficiently hard, no interference of flat laying through after-shrinkage will occur.

Cost Comparison

A cost comparison for the manufacture of LP-PE and of HP-PE sheets is given in table 3. With identical capital costs and also identical fixed and variable costs, the production costs for LP-PE sheets are 50% higher than those for HP-PE sheets of equal thickness. Considering that HD-PE sheets are generally produced and used thinner than LP-PE and by reducing the sheet thickness to two thirds of the thickness assumed for HP-PE, identical production costs per area unit result.

IV. Properties of LP-PE Sheets

When explaining the term "paperlike" it was stated that this term was not meant to include all properties of paper. Sheets used for packaging generally have **several** advantages over paper in particular impermeability to water, water vapour and gases, wet strength and chemical resistance, also weldability, i.e. sealability LP-PE sheets in particular have these advantages over paper.

Properties valued with paper i.e. good printability, stiffness, foldability and creasability which all make for good processability on fast machines, are shared by LP-PE sheets to a much higher degree than by any other type of sheet competing with paper in the packaging field, particularly HP-PE sheets. A qualitative comparison is given in table 4 and more detailed information about properties quoted in table 5.

Table 5 shows the basic superiority of plastic sheets over paper in their tear and elongation performance, their impermeability and impact strength. Particularly when comparing high and low molecular LP-PE, the low tensile and impact strength of the low molecular is significant. Fig. 7 gives a comparison of stiffness with papers - a very important property for further processing -, which shows that LP-PE sheets have on average about 50% of the stiffness of paper of equal thickness, whilst HP-PE sheets reach only approx. 10% of the stiffness of paper.

Fig. 8 shows shrinkage curves from which it can be seen clearly that such sheets could under certain circumstances be used as shrink-film. It should be mentioned that they can also be sterilized.

V. Further Processing

Further possible processing methods largely depend on sheet properties.

For printing the sheet has to be pre-treated with Corona discharge, as is usual practice with polyolefines. One standard pre-treatment is already yielding execellent results. If required, weldability of the sheet with test inks of a surface tension exceeding 50 dyn/cm can be achieved. This satisfies the requirements of all printing methods and also those of laminating. Printing of these sheets may be carried out by the flexo, gravure, or offset-method. The resulting print is surprisingly sharp and adheres well due to the "fine-rough" surface. The printing inks are not only anchored to the surface by adhesion and by chemical bonds, but also purely mechanically. Fig. 9 shows surface profiles of HP-PE and LP-PE sheets. The roughness depth of paperlike sheets made from LP-PE corresponds to that of fine papers, whereby the number of unevennesses calculated on length is even greater.

Multicolour printing, particularly of thin sheets may cause difficulties under certain circumstances, owing to possible wrinkling and warping of the sheets. It is advisable to use anti-wrinkle expanders in all cases and if possible to carry out multicolour printing on machines with a common back-pressure roller. Printing inks suitable for PE-sheet have been found very suitable, paper-printing inks too showed excellent adhesion when test printed. The sheets must be dried immediately after printing. In contrast to paper this cannot be avoided, because the sheets are not so absorbent as paper.

There are no problems with welding of LP-PE sheets into bags. This can be done by butt or by hot wire welding, whereby some rules should be observed: The welding temperatures are to be selected slightly higher than for HP-PE sheets. The seam may shrink owing to the high stretching ratio of the sheet in both directions. The resulting wavyness of the welding seam is particularly noticeable with LP-PE sheets, owing to their greater stiffness. To prevent this shrinkage, welding is usually carried out with pre-tension applied in the direction of welding.

For bonding and laminating largely the same factors apply as for printing. A pre-requisite for perfect adhesion is a good pre-treatment of the sheet. On testing, several single and two component adhesives were found to be suitable. However, LP-PE sheets are not yet being processed further by a method required bonding. Therefore no works experience on HM-sheets is available. It cannot be stated today, whether it will be possible to fulfil the request made on many occasions, to bond LP-PE on conventional paper processing machines. At any rate HM-sheets cannot be bonded with adhesives on an aqueous basis, but only with those on a solvent basis, which necessitates drying of the adhesive coating prior to bonding.

Nothing is known so far about the use of paperlike LP-PE sheets in the deep-drawing and shrink-processes, however, these sheets are well suited for both processes.

VI. Applications

The discussion of ranges of applications for LP-PE sheets should not be restricted to known cases, but ought to extend to areas where new applications may be expected with certainty.

Present day applications are shown in table 6.

An interesting application for bags is the welded cheap one-way packing for medical instruments, suitable for sterilization, also suitable for hospital and hotel requirements. Such packagings are extremely useful owing to the necessary rationalization caused by lack of personnel.

Deep freeze packaging will also become more important, because deep frozen goods can be warmed up in their packaging. This type of packaging can also be written on much more easily than LP-PE packaging. It is not possible at present to use LP-PE sheet for the manufacture of carrier bags for food, however some real possibilities exist for special carrier bags e.g. for textiles, records and in the book trade, particularly in competition with specially treated papers. The problems are the higher price for LP-PE compared with paper and also the unsolved manufacturing problems, particularly that of bags with reinforced bottoms. There are at present no further ranges of applications, but a short survey of real possibilities is given below.

There will be application for thin sheets by laminating them to paper and cardboard, in order to seal the paper or cardboard surface and also to render them weldable. This applies e.g. to the well known "party crockery" and to the manufacture of washable wall papers, both with the possibility of counter-print.

Further possible applications of thin sheets are in laminates with aluminium foil to produce compound foils.

There are great possibilities in packaging whenever expensive compound sheets also containing multiple layers of paper are to be replaced by a single layer of thicker sealable HM-sheet.

This would for instance be possible for packaging of food, sugar, leguminosae, rolls, seeds, tobacco and cigarettes, soap and toiletries.
Similarly it is possible, whenever the price permits, to replace the customary packaging paper, e.g. for packing of underwear, textiles, records, and many other expensive articles.

An interesting application would be its use as separator e.g. in the manufacture of rubber as embossed separating sheet, or as separating sheet for self-adhesive labels.

Undoubtedly it will be possible to consider the use of thicker LP-PE sheets in the graphic industry at a future date. However some problems will have to be solved first e.g. flat laying, opacity and stiffness.

VII. Market Evaluation

No actual and reliable figures for market evaluation can be quoted so far, however some observations and considerations permit a clear picture of future trends to be gained.

Whilst the price level of the raw material market for plastics has been stable, almost slightly regressing, during the last years and is likely to remain so in future, there occur in contrast to it steady increase of prices in the paper and paper raw material sector. The value and quantity growth rates for packaging materials made from paper were in 1970 also clearly lower than those for comparable plastic products.

An example from the fibre production may be considered typical for the replacement of natural products by synthetic ones. In 1950 the promotion of synthetic fibres of the total world fibre requirement was only 0.2%. It had risen by 1970 to 22%. It will not be possible to transfer this example by way of absolute figures, but it does show the trend of progress of synthetic papers on the market.

The first production plants in Europe have come on stream already and we are convinced that a considerable increase in the requirement for paperlike polyethylene sheets will take place.

Table 1. Connection between melt index and sheet properties

Melt index MFI 190/5 (g/10 min)	Minimum sheet thickness (μm)	Maximum possible blow-ratio	Tensile strength along / across	Evaluation of sheet
0.2 to 0.6 (high molecular)	10	1 : 10	levelled out	high tensile strength well levelled out along and across, great stiffness, matt surface, high tear and further tear strength
1.5 to 5.0 (lower molecular)	5	1 : 5	longitudinally oriented	lower tensile strength not levelled out along and across, low stiffness, glossy surface, low tear and further tear strength

Table 2. Characteristics for the manufacture of paper-like sheets from high molecular low pressure polyethylene

Peculiarity of process	Consequence	Technical process requirements
low processing temperatures, high molecular LP-PE	tendency to shearing, tendency to orienting high pressure build up	careful melting (screw design), ideal design of flow path, great capacity to accept pressure
high blowing ratio, blowing partly below the crystallite melt region	difficulties with hose guilding	small nozzle diameter, sensitive, exact hose cooling (under circumstances calibrating) broad flat laying and winding
manufacture of extremely thin and stiff sheets	difficult flat laying, formation of wrinkles and windings containing wrinkles	laying flat while warm, low take-off speed, keeping width, sensitive winding gear

Table 3. Comparison of costs and manufacture of LP-PE and HP-PE sheets

	HP-PE	LP-PE	ratio HP-PE LP-PE
Invested capital A	1.0	1.0	1.0
Output (kg/year) B	1.8	1.0	1.8
Price B	0.67	1.0	0.67
Material and general costs C	1.2	1.0	1.2
Fixed costs D	1.0	1.0	1.0
Variable costs E	1.0	1.0	1.0
Manufacturing comparison (C+D+E)/B	0.67	1	0.67

Table 4. Properties of LP-PE sheets compared to paper and HP-PE sheets

	Standard paper	High molecular LP-PE-sheet	HP-PE sheet
Price	very favourable	medium	very favourable
Initial tear strength	good	very good	medium
Further tear strength	medium	very good	medium
Wet strength	poor	as dry	as dry
Elongation at break	almost none	good	very good
Stiffness	very high	high	low
Printability	very good	good	medium
Dimensional stability during processing	very good	very good	medium
Weldability	none	very good	very good
Tightness to water and gases	none	good	good
Bondability	very good	good	good
Foldability and creasability	very good	good	poor
Working properties on machines	very good	good	medium

Table 5. Properties of various sheets compared to paper

	HP-PE sheet	Standard paper	LP-PE sheet high molecular (HM-sheet) along / across	LP-PE sheet low molecular along / across
Tensile strength (DIN 53 455) (kp/cm^3)	150 to 200	70 to 250	450/350	330/260
Elongation at break (DIN 53 455) (%)	600	5	650/450	500/440
Initial tear strength (DIN 53 455) (P/100 µm)	800	320 to 600	3200/2700	2000/1900
Impact tension strength (DIN 53 448) (kp cm/cm^2)	2000	50 to 200	2000/1800	350/750
Water vapour permeability 25 µm sheet at 20 °C, 85 % r.h. (DIN 53 122) (g/m^2 24 hours)	3	extremely permeable	1 to 1.5	1 to 1.5
Oxygen permeability (aroma tightness . $\frac{\text{cm}^3\text{ (NTP)}}{\text{m}^2\text{ 24 h.atm.}}$	650	extremely permeable	2900	2900
Maximum service temperature (short time service value in brackets) (°C)	80 to 90 (95)	180 to 200	110 to 115 (120)	110 to 115 (120)

Table 6. **Application for paperlike sheets of LP-PE**

Range of application	Set-up	Thickness (μm)
Wrapping sheets for food (meat and sausages, fish, dairy products, interleaving for sliced packed cheese and confectionery, sweet wrapping	sheets 10 to 30 μm thick of medium and high molecular ND-PE cut or on rolls, printed or plain	10 to 15
for flowers		10 to 20
for laudries and dry cleaners		15 to 30
for presentation papers		15 to 30
Bags for food (fruit, vegetables, confectionery, meat and sausages, fish and dairy products), for textiles, paper and stationery, tobacco, sundries, dispensing chemists and departmental stores	sheets 10 to 30 μm thick mainly for high molecular ND-PE, flat and side gusseted bags, printed or plain, mainly welded also as bags to be torn off a roll	10 to 25 15 to 25
for household "keep fresh" and deep freeze packages		15 to 25
welded and suitable for sterilizing for medical instruments, pharmaceutical and tropical packages and for the hotel industry		15 to 30
carrier bags for textile department stores, dispensing chemists, book sellers, records, stationers, shoe shops	sheets 20 to 50 μm thick of high molecular ND-PE printed or plain, mainly welded	20 to 50

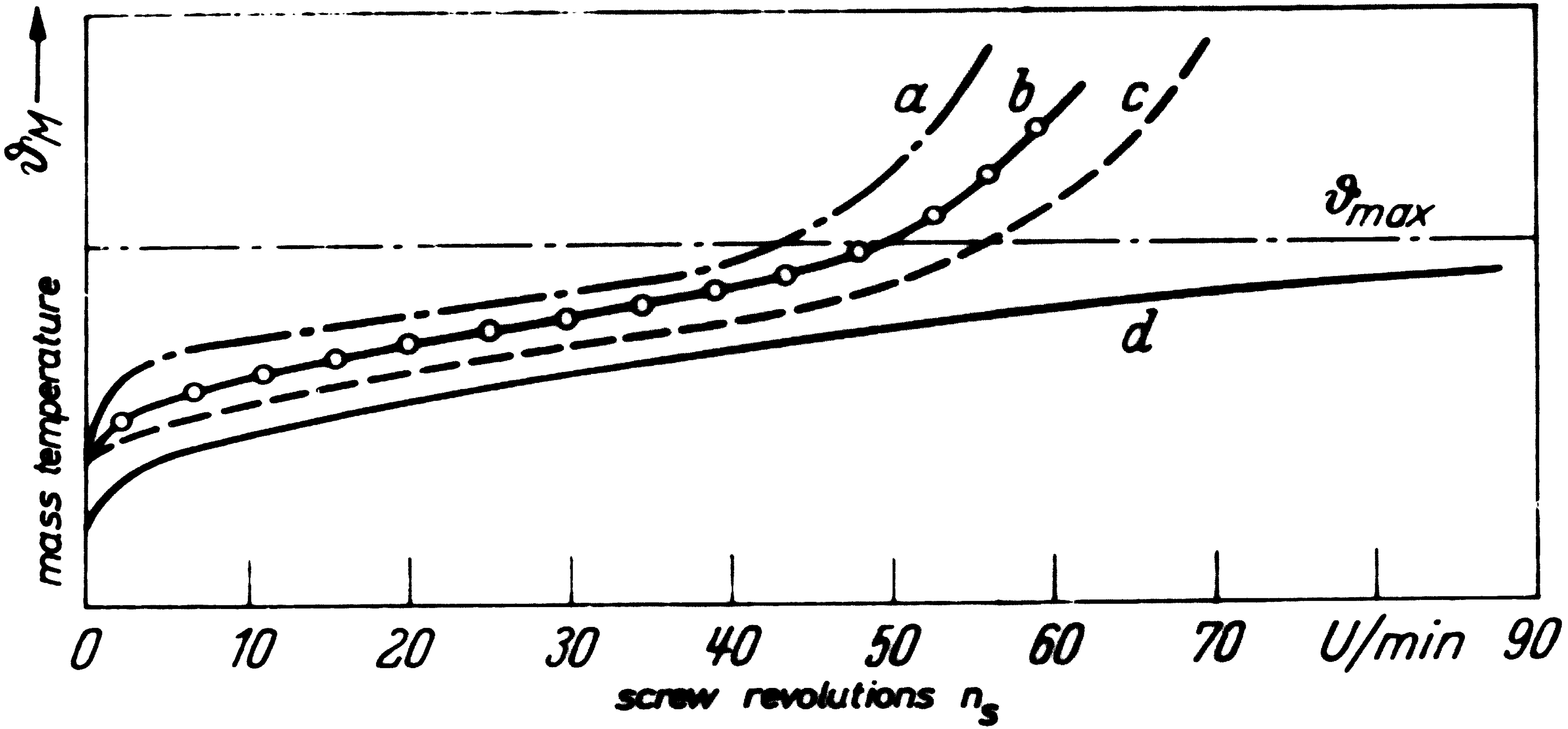


Fig. 1. Connection between screw revoltions and mass temperature.
ϑ_{max} = maximum permissible mass temperature

a,b,c: Three zone screw with compression and pressure relief zone
d = modified three zone screw with compression and pressure relief zone (corresponding to Fig. 2)

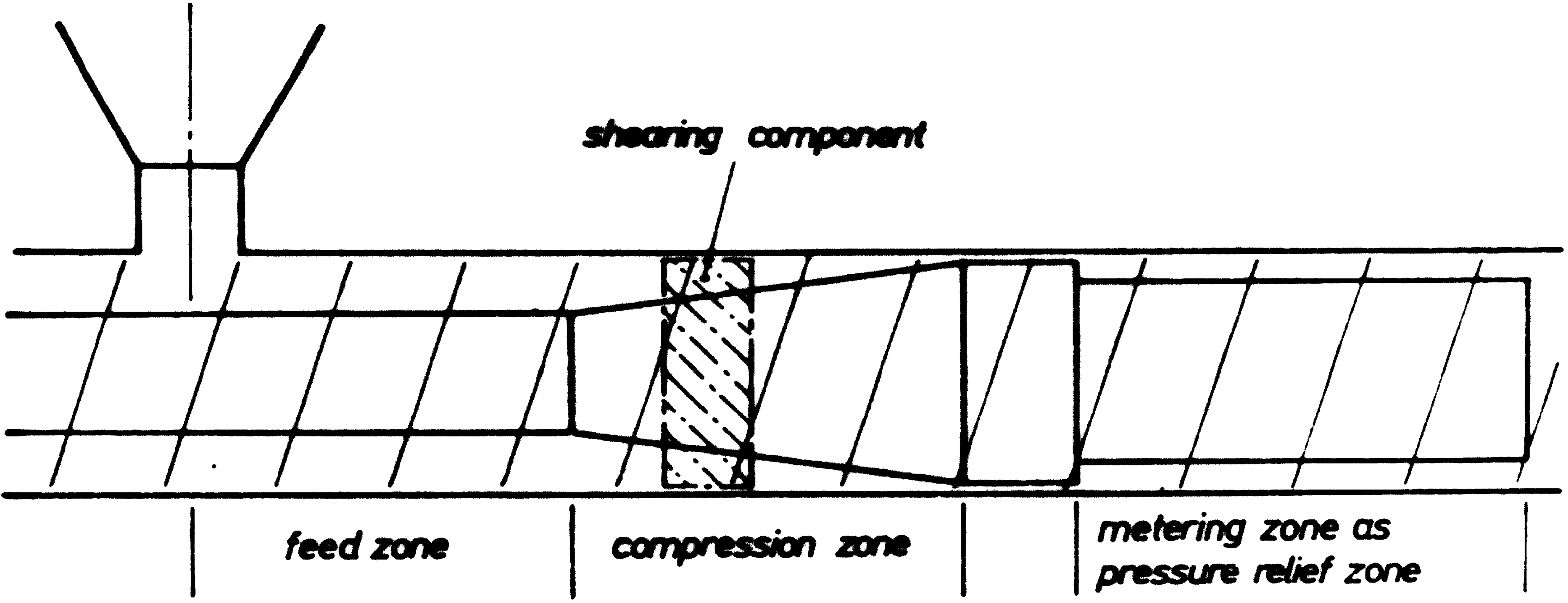


Fig. 2. Modified three zone screw for the manufacture of LP-PE sheet

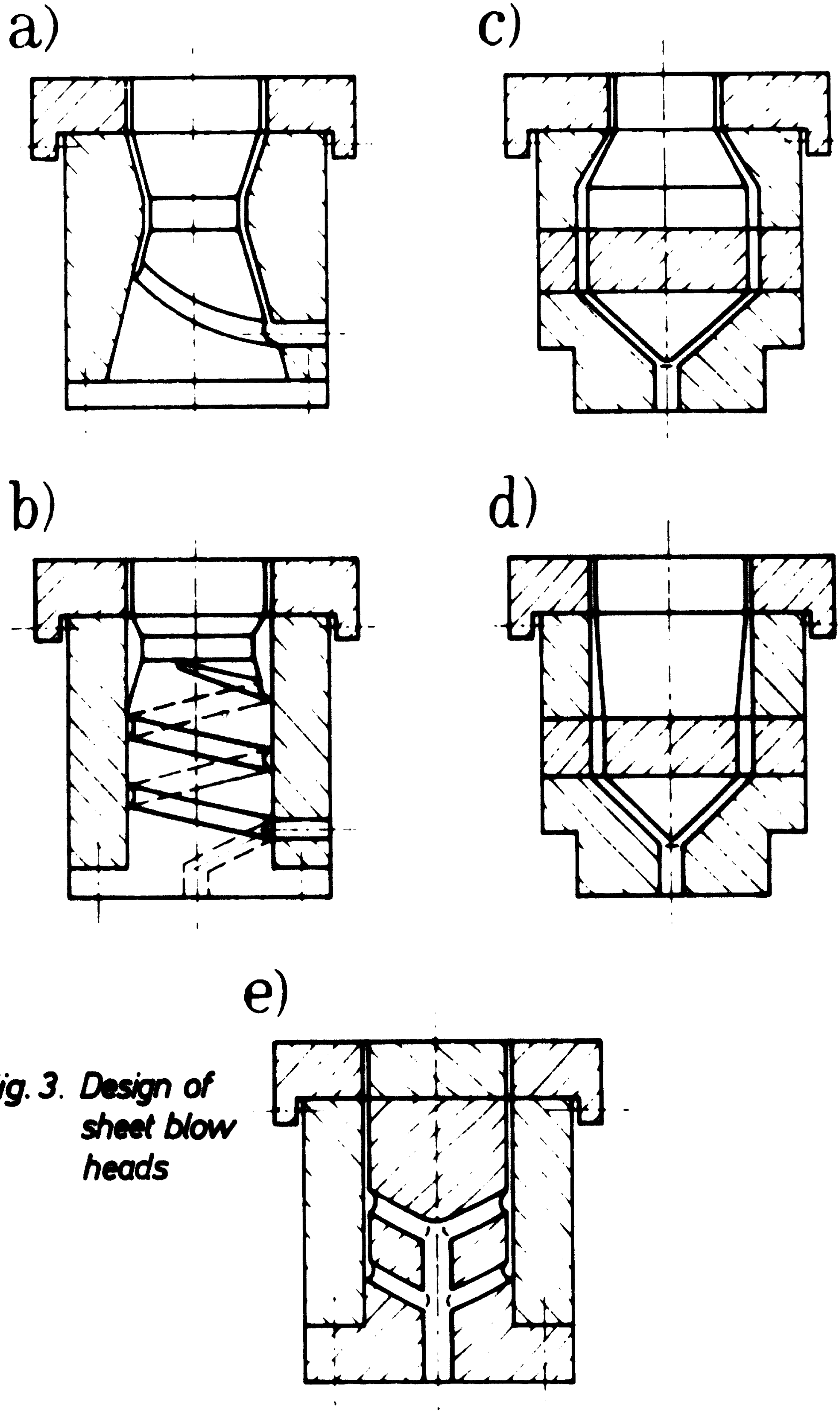


Fig. 3. Design of sheet blow heads

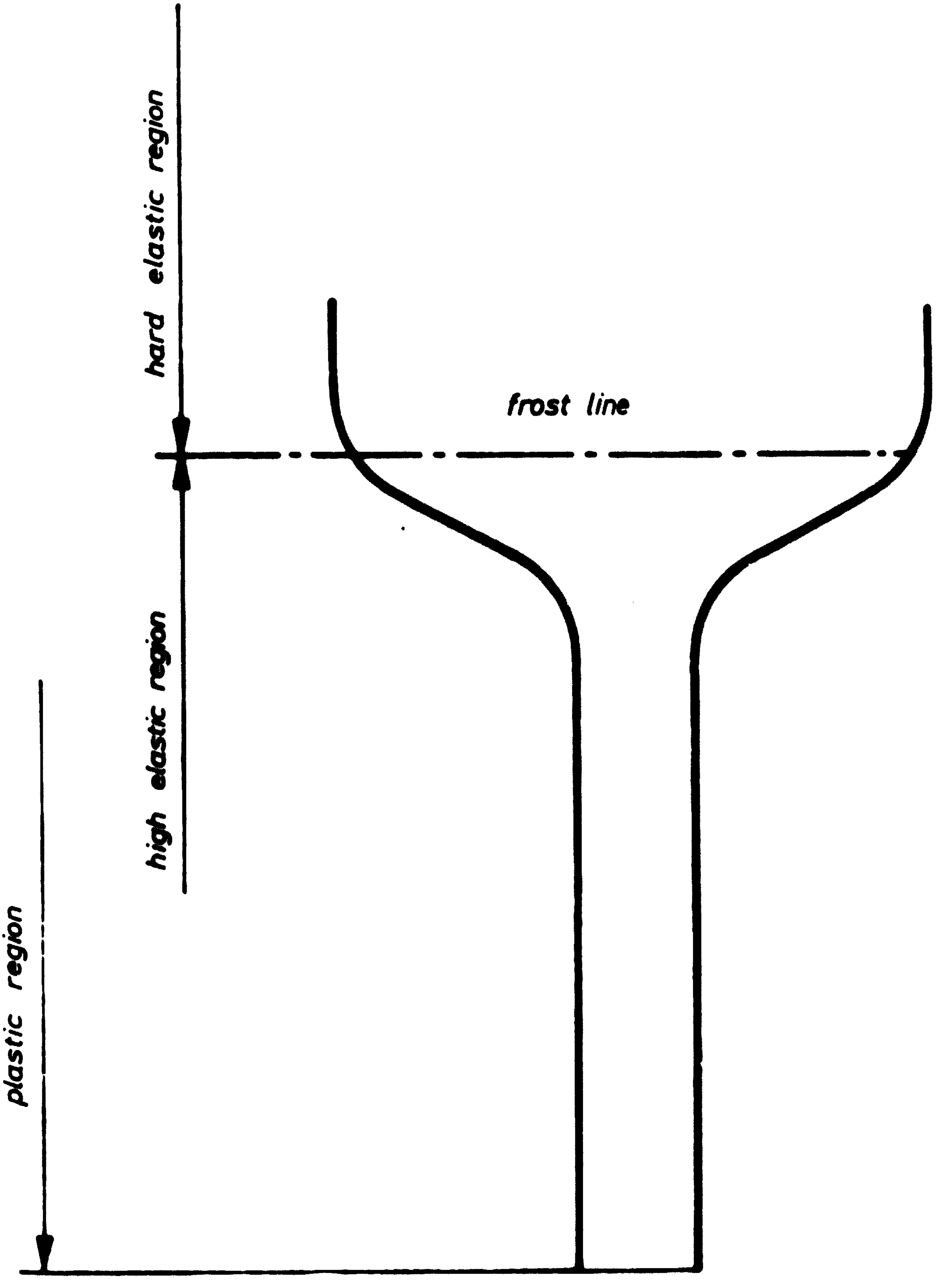
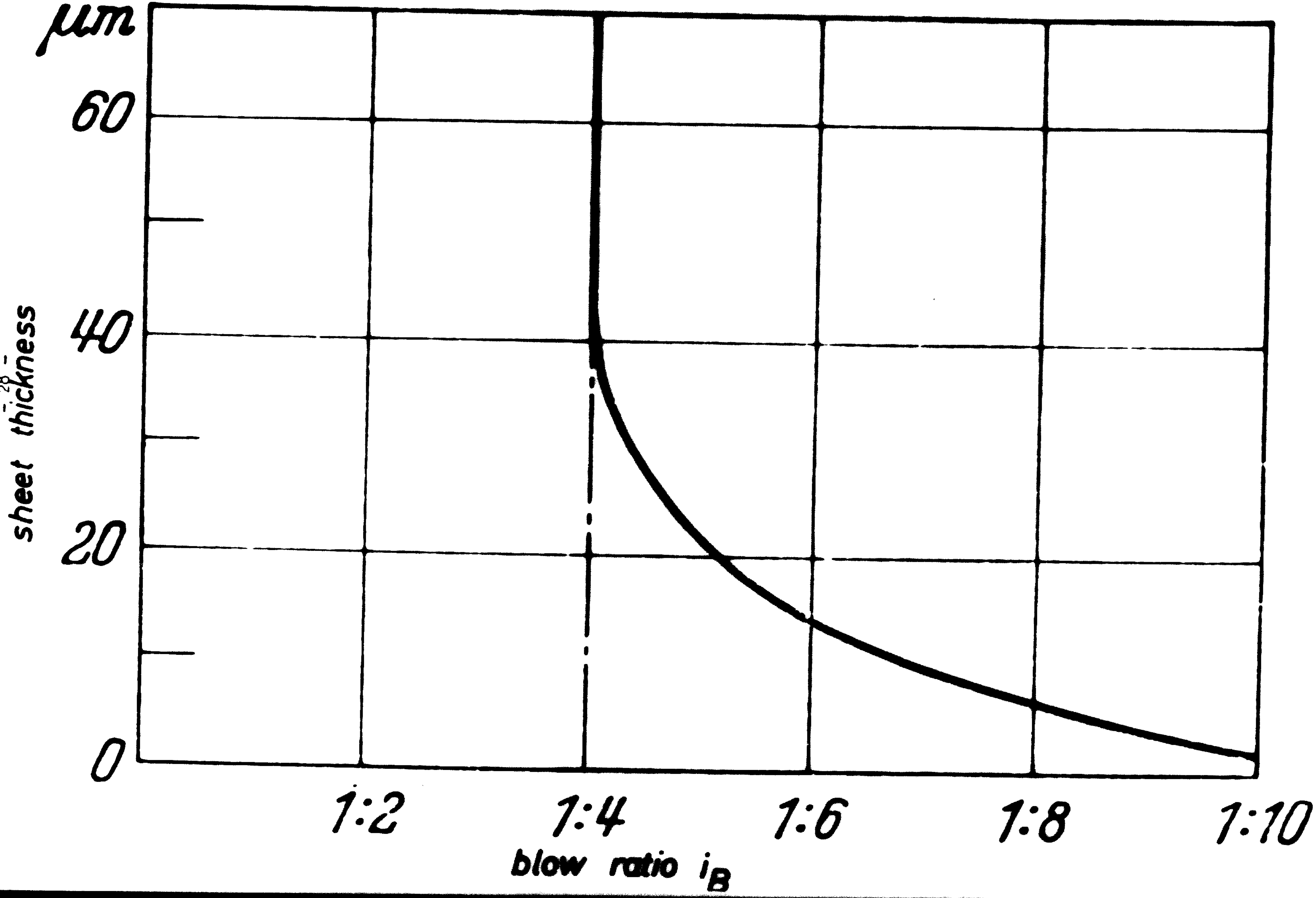


Fig. 4. Blowing and take off ratios

Fig. 5. Connection between sheet thickness and blow ratio



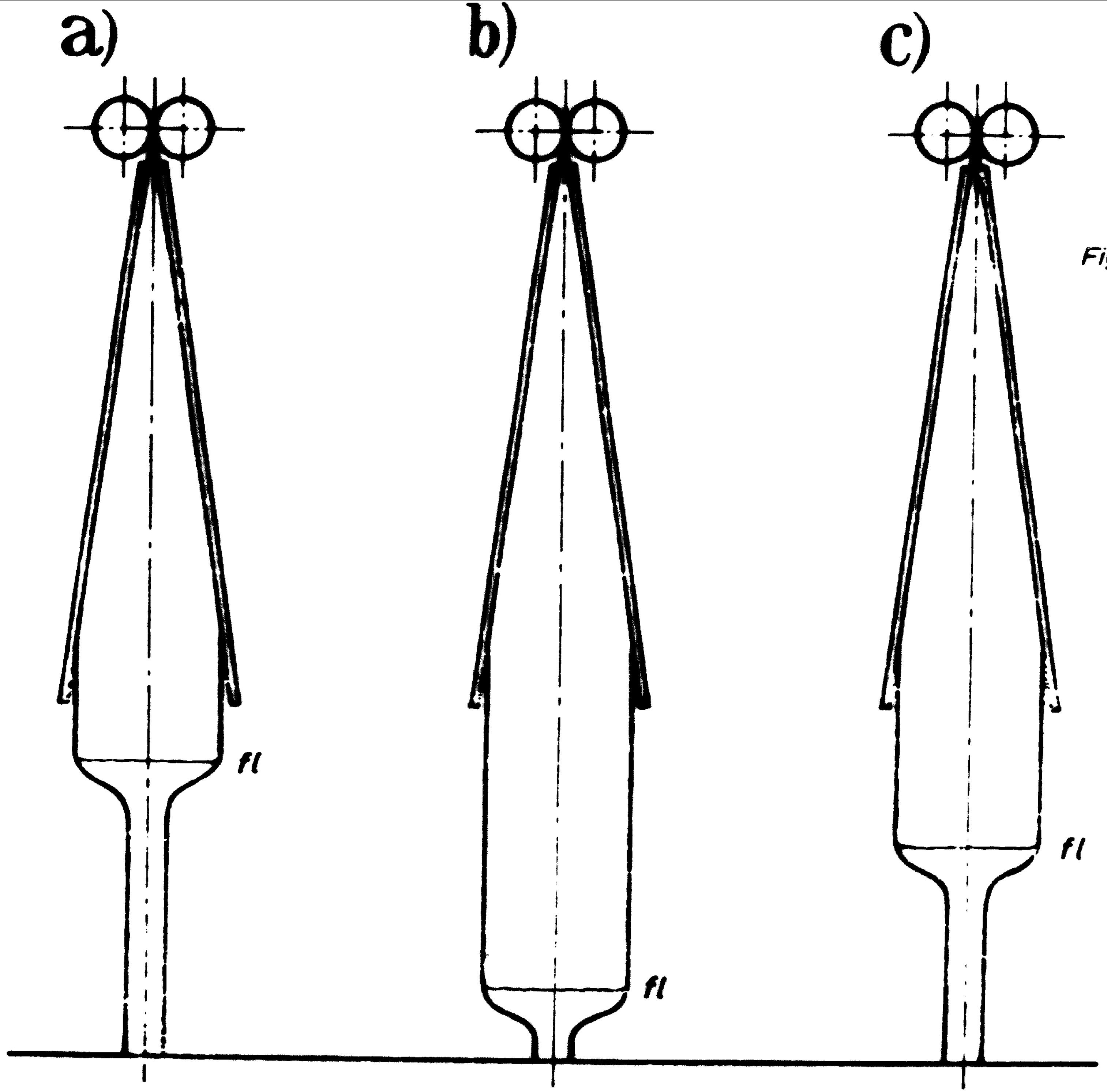


Fig. 6. Setting variables of frost line Fig. 1. For explanation see text

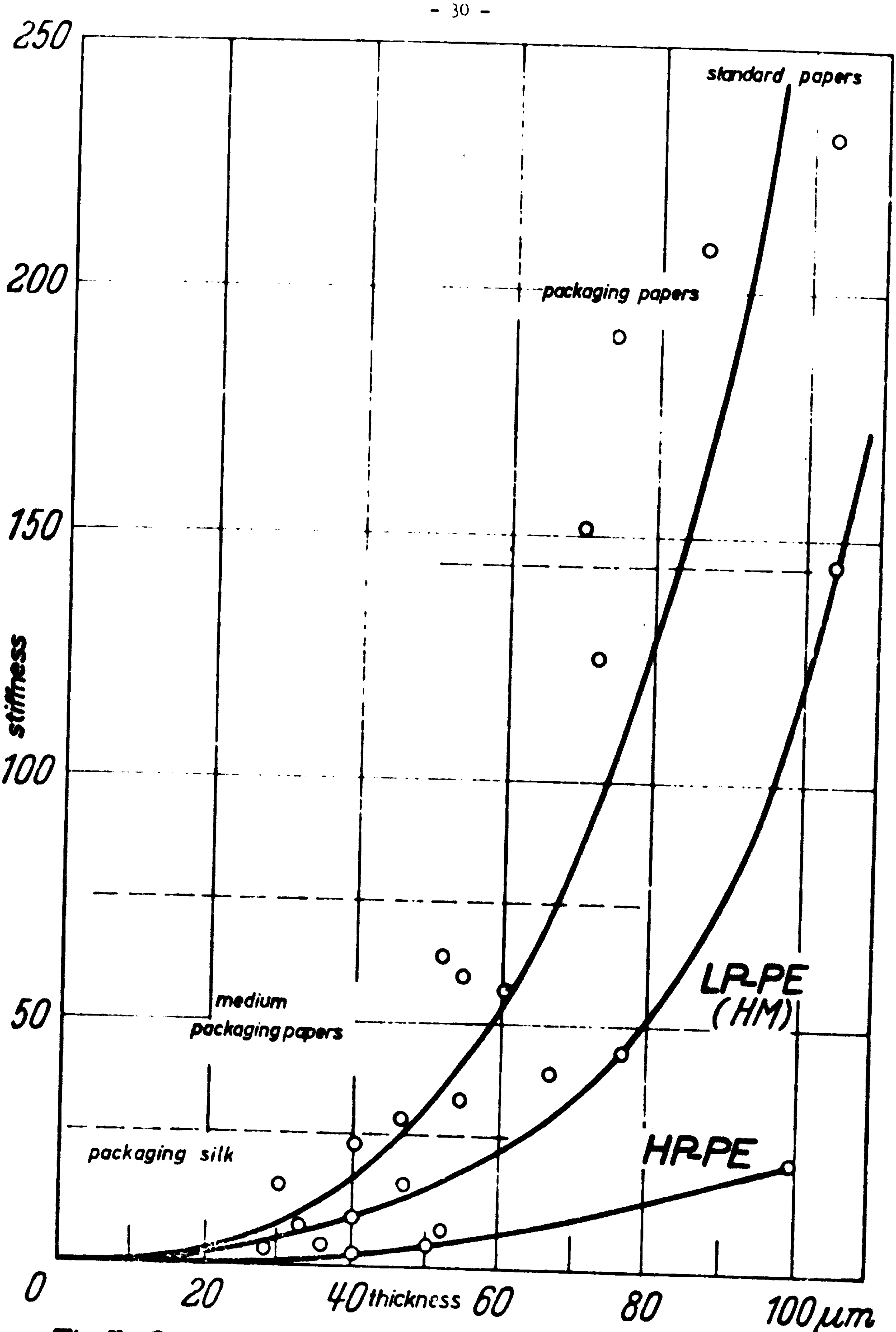


Fig. 7. Stiffness of PE-sheets compared to paper
(Handle-O-meter-values)

Fig. 8. Shrinkage behaviour of LP-PE sheet (10 seconds in glycol bath)

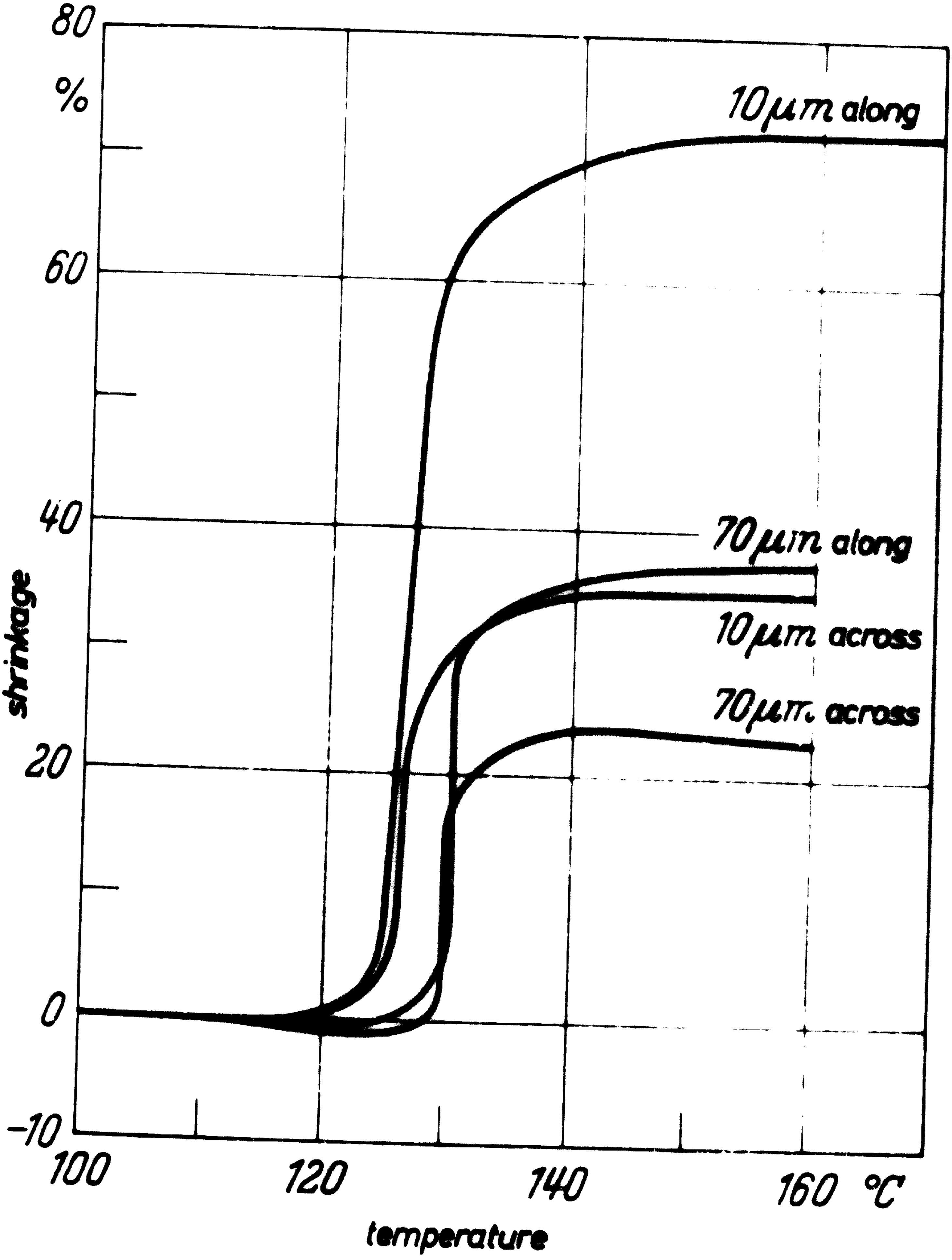
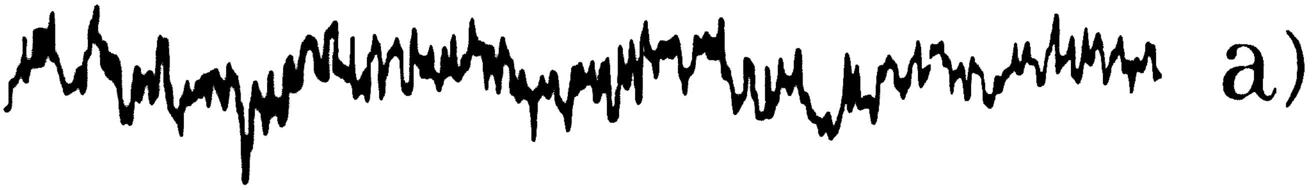
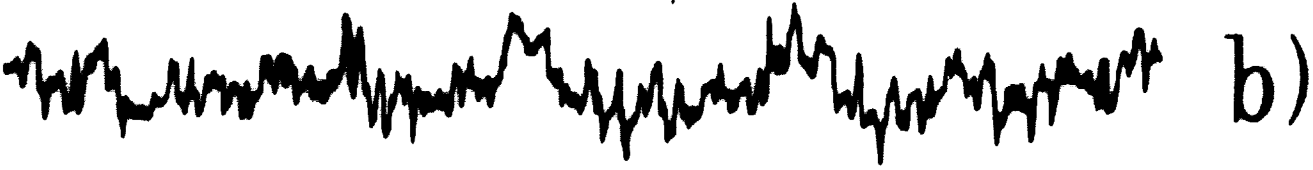


Fig. 9. Roughness depth profile of PE sheets

a) HM-sheet, outside, along (R_1 = 0.55 µm)



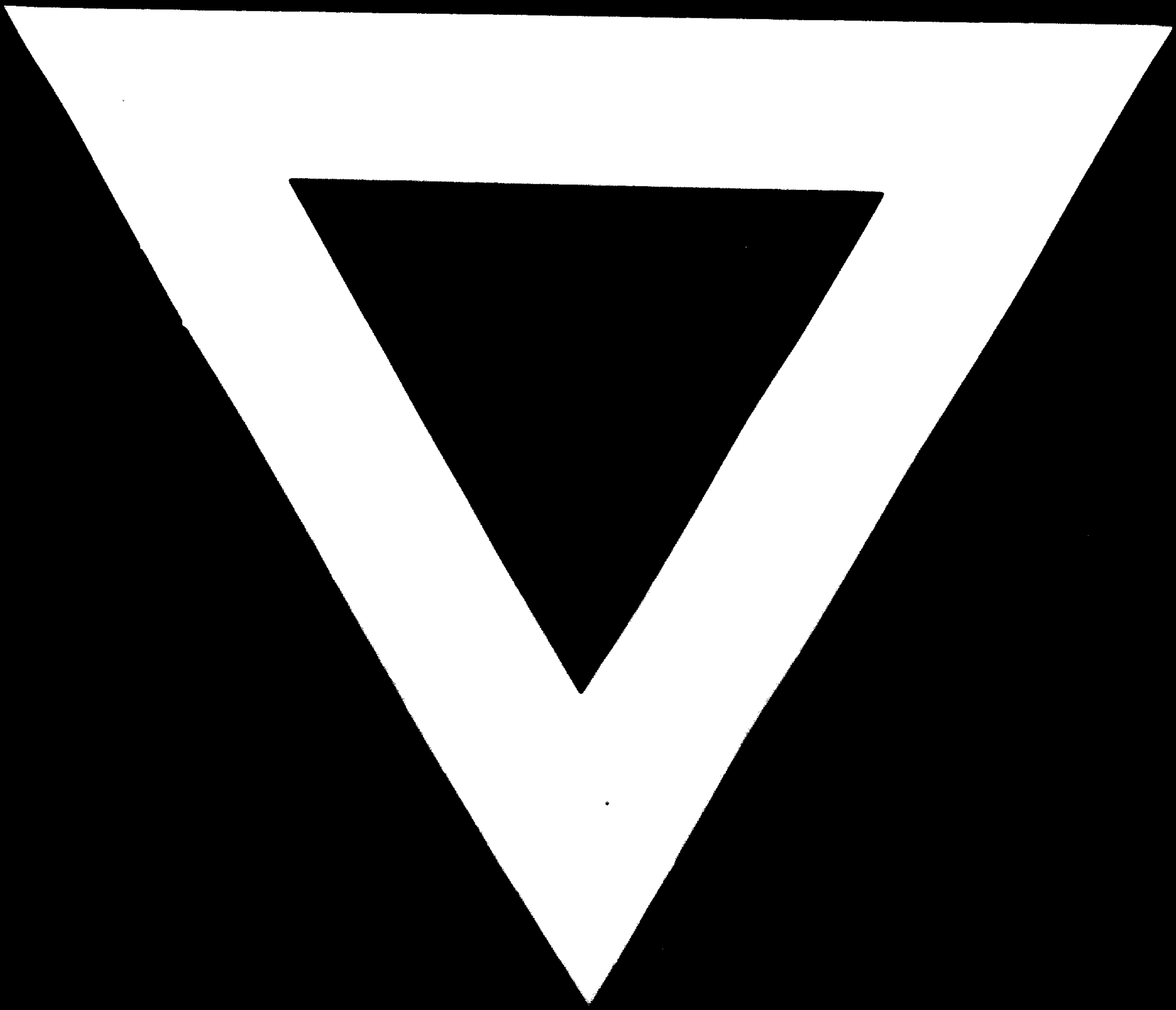
b) HM-sheet, outside, across (R_1 = 0.55 µm)



c) HM-sheet, inside, along (R_1 = 0.65 µm)

d) HM-sheet, inside, across (R_1 = 0.52 µm)

e) HP-PE-sheet (R_1 = 0.45 µm)



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